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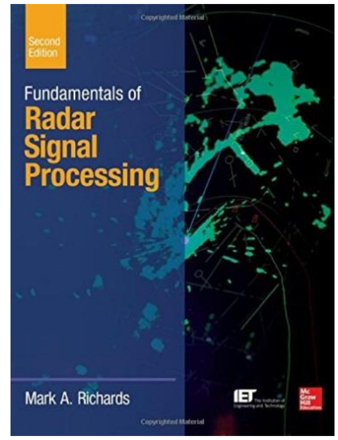
Errata for all Printings



Fundamentals of Radar Signal Processing, second edition

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The author wishes to thank the many students and readers who will, no doubt, help to identify errata in the text. The responsibility for all errors, both those that have been found and those yet to be found, lies entirely with the author.

Page	*Location on Page*	*Correction*
59	Table 2.3	• In the "comment" column for the Weibull case, change "Can have longer "tail" than previous cases." to "Can model long-tailed or "spiky" data." • In the "comment" column for the Weibull case, change " "Tail" is longest of previous cases." to "Can model long-tailed or "spiky" data."
60	1st line of text	• Change "chi-square and K distributions." to "chi-square distributions of arbitrary order and K distributions."
62	Table 2.4	Several corrections to table entries: • Nonfluctuating case, "Comment" column: Change to "Also nonfluctuating model, one parameter changed: $\bar{\sigma} \to \sqrt{\bar{\sigma}}$ • Central chi degree 4 case: Correct the expression for the mean to read $\bar{\zeta} = \frac{3}{4}\sqrt{\frac{\pi\bar{\sigma}}{2}}$ • Central chi, degree 2*m* case: Correct the expression for the mean to read $\bar{\zeta} = \frac{\Gamma(m+0.5)}{\Gamma(m)}\sqrt{\frac{\pi\bar{\sigma}}{m}}$ • Rice case, "RCS Model Name" column: change "chi-square" to just "chi". • Rice case: delete the subscript "1" from the e^{-a^2} term in the expression for the mean $\bar{\zeta}$. • Rice case, "Comment" column: Change "${}_1F_1(x)$ to ${}_1F_1(\alpha,\beta,x)$. • Weibull case: In the expression for $\mathrm{var}(\zeta)$, change the term $B^{-1/2C}$ to $B^{-1/C}$. • Log-normal case: Change the exponential term in the forumal for the PDF from $\exp\left[-2\ln^2\left(\zeta/\sqrt{\sigma_m}\right)^2/s^2\right]$ to $\exp\left[-4\ln^2\left(\zeta/\sqrt{\sigma_m}\right)^2/s^2\right]$.

Page	***Location on Page***	***Correction***
63	Eq. (2.56)	The left parenthesis should appear after the symbol Ω in the first line, not before it. The corrected equation is $$\bar{y}(t) = \sum_{n=-M}^{M} Ae^{j\Omega\left(t-2\left(R_0+n\Delta x\sin\theta\right)/c\right)}$$ $$= Ae^{j\Omega(t-2R_0/c)} \sum_{n=-M}^{M} e^{-j4\pi n\Delta x \sin\theta\, F/c}$$
82	Third line before Eq. (2.84)	P_0 should be P_o (the subscript should be an italic lower-case letter 'o' instead of a non-italic numeral zero).
87	Second line after Eq. (2.97)	The term $-\left(1+\beta_v\right)4\pi/\lambda R_0$ should instead be $-\left(1+\beta_v\right)\left(4\pi/\lambda\right)R_0$, i.e. the R_0 belongs in the numerator.
114	First paragraph and Eq. (3.9)	This section is conflating unambiguous range and the beginning of the blind range zone. Unambiguous range should be defined based on the periodicity of the range response. Consequently, Eq. (3.9) should be simply $$R_{ua} = \frac{cT}{2} = \frac{c}{2PRF}$$ and the 2nd and 3rdf sentences in the first paragraph should be replaced with "In particular, the maximum range from which an echo of the leading edge can be received before the next pulse is transmitted is the *unambiguous range*. It must satisfy $2R_{ua}/c = T$, so"
166	Eq. (4.79)	The lower limit on the summation should have *M* instead of *m*. The corrected equation is $$A(t,0) = \begin{cases} \sum_{m=-(m-1)}^{M-1} (M-\lvert m\rvert)\left(1-\frac{\lvert t-mT\rvert}{\tau}\right) & \lvert t-mT\rvert < \tau \\ 0 & \text{elsewhere} \end{cases}$$
230	Last line preceding Eq. (5.29)	Change $\left(\sigma_n^2 \gg \sigma_n^2\right)$ to $\left(\sigma_c^2 \gg \sigma_n^2\right)$
301	Eq. (6.19)	The left hand side of the equation is the complementary error function, not the error function itself. The corrected equation is $$\operatorname{erfc}(x) \equiv \frac{2}{\sqrt{\pi}} \int_x^{+\infty} e^{-t^2}\,dt = 1-\operatorname{erf}(x)$$

Page	***Location on Page***	***Correction***
301	Eqs. (6.20) and (6.21), and last line of text before (6.20)	The variable representing noise power is σ_w^2, not β^2. The corrected text and equations are: text: "With the change of variables $t = \Upsilon / \sqrt{2N\sigma_w^2}$, Eq. (6.17) can be written as" (6.20): $\alpha = P_{FA} = \frac{1}{\sqrt{\pi}} \int_{T/\sqrt{2N\sigma_w^2}}^{+\infty} e^{-t^2} dt = \frac{1}{2}\left[1 - \operatorname{erf}\left(\frac{T}{\sqrt{2N\sigma_w^2}}\right)\right]$ (6.21): $T = \sqrt{2N\sigma_w^2}\, \operatorname{erf}^{-1}(1 - 2P_{FA})$
307	3rd line in section 6.2.1	change KT to kT
311	Eqs, (6.40) and (6.42)	Change **E** to E in the exponential in both equations.
312	2nd line of text before Eq. (6.45)	Change σ_{w}^2 to σ_w^2.
313	First line of text after Eq. (6.48)	Change $E\sigma_w^2 \sim \mathrm{N}\left(E, E\beta^2\right)$ to $\tilde{\mathbf{m}}^H\mathbf{y} \sim \mathrm{N}\left(E, E\sigma_w^2\right)$. Also, in the next two lines of text, change $\mathrm{N}\left(E, E\beta^2/2\right)$ to $\mathrm{N}\left(E, E\sigma_w^2/2\right)$, and $\mathrm{N}\left(0, E\beta^2/2\right)$ to $\mathrm{N}\left(0, E\sigma_w^2/2\right)$.
313	Text before and after Eq. (6.49)	Replace the last two sentences preceding (6.49) in their entirety with the following: "For a particular target and thus a particular value of θ, the real and imaginary parts of $\tilde{\mathbf{m}}^H\mathbf{y}$ are distributed respectively as $\mathrm{N}\left(E\cos\theta, E\beta^2\right)$ and $\mathrm{N}\left(E\sin\theta, E\beta^2\right)$. Regardless of the value of θ, the PDF of $z = \left\lvert\tilde{\mathbf{m}}^H\mathbf{y}\right\rvert$ is then"
323	Footnote 12	The definition of the incomplete gamma function in Eq. (6.80) on p. 322 is *not* consistent with that used in the MATLAB® `gammainc` function. Following is the correct relationship: $I(\mu, M) = \texttt{gammainc}\left(\mu\sqrt{M+1}, M+1\right)$ It follows that the right hand side of Eq. (6.79) is expressed in MATLAB as $\texttt{1-gammainc}\left(T, N\right)$, a simpler expression that I'll probably switch to in the next edition.

Page	***Location on Page***	***Correction***
323	Eq. (6.85)	The denominator of the first term on the right-hand side should be the product $N\chi$, not N_χ. The corrected equation is $$p_{z'}(z'\|H_1)=\left(\frac{z'}{N\chi}\right)^{\frac{N-1}{2}}\exp\left(-z'-N\chi\right)I_{N-1}(2\sqrt{N\chi z'})$$
323	Eq. (6.86)	The denominator of the first term in the integral on the right-hand side should be the product $N\chi$, not N_χ. The corrected equation is $$P_D=\int_T^{\infty}\left(\frac{z'}{N\chi}\right)^{\frac{N-1}{2}}\exp\left(-z'-N\chi\right)I_{N-1}(2\sqrt{N\chi z'})\,dz'$$ $$=Q_M\left(\sqrt{2N\chi},\sqrt{2T}\right)+e^{-(T+N\chi)}\sum_{r=2}^{N}\left(\frac{T}{N\chi}\right)^{\frac{r-1}{2}}I_{r-1}\left(2\sqrt{N\chi T}\right)$$
324	Eq. (6.87)	The value 5.54 in the second line of the equation should be changed to 4.54. The corrected equation line is $$\chi_1=-5\log_{10}N+\left[6.2+\left(\frac{4.54}{\sqrt{N+0.44}}\right)\right]\cdot\log_{10}(A+0.12AB+1.7B)\text{ dB}$$
330	Table 6.1, "Case 4" entry	This is not an error, but for improved clarity, change the P_D equation from $$\left\{c^N\sum_{k=0}^{N}\frac{N!}{k!(N-k)!}\left(\frac{1-c}{c}\right)^{N-k}\right\}\left\{\sum_{l=0}^{2N-1-k}\frac{e^{-cT}(cT)^l}{l!}\right\},\quad T>N(2-c)$$ $$1-\left\{c^N\sum_{k=0}^{N}\frac{N!}{k!(N-k)!}\left(\frac{1-c}{c}\right)^{N-k}\right\}\left\{\sum_{l=2N-k}^{\infty}\frac{e^{-cT}(cT)^l}{l!}\right\},\quad T<N(2-c)$$ to $$c^N\sum_{k=0}^{N}\left(\sum_{l=0}^{2N-1-k}\frac{e^{-cT}(cT)^l}{l!}\right)\frac{N!}{k!(N-k)!}\left(\frac{1-c}{c}\right)^{N-k},\quad T>N(2-c)$$ $$1-c^N\sum_{k=0}^{N}\left(\sum_{l=2N-k}^{\infty}\frac{e^{-cT}(cT)^l}{l!}\right)\frac{N!}{k!(N-k)!}\left(\frac{1-c}{c}\right)^{N-k},\quad T<N(2-c)$$
334	Table 6.3	The correct value of P_C in the last row (p = 10^{-6}) is 6.0×10^{-12}, not 6.0×10^{-10}.
366	Problem 18	Change "Assuming the interference power exactly …" to "Assuming the interference power is known exactly …".
450	Equation (8.7)	The middle line of this equation should be changed to $$=e^{j\Omega t}e^{-j4\pi R/\lambda}\sum_{n=-M}^{+M}\exp\left[j2\Omega nd\sin\theta/c\right]$$

Page	***Location on Page***	***Correction***
489-490	Equation (8.78) and Fig. 8.38	Eq. 8.78 does not follow from Fig. 8.38. The correction involves a change to the figure and several scattered text changes to these two pages. Rather than try to list each individual change, at the end of this errata list I have included an update to the entire affected part of these two pages.
563	2nd line of text before Eq. (A.45)	Change $N\left(x;\sigma\mu_i,\sigma^2\right)$ to $\mathrm{N}\left(x;\sigma\mu_i,\sigma^2\right)$
571	1st line of text	Change μ to **μ** (boldface to indicate a vector)
571	Last line of text before Eq. (A.83)	Change “(A.92)” to “(A.81)”.
		Your Erratum Here!

Correction to portions of Section 8.6.1, "The Effect of Height on a SAR Image", beginning p. 489 (second edition) or p. 437 (first edition). Includes corrections to text and equations, and modification of Fig. 8.38.

NOTE: Equation numbers correspond to second edition; in the first edition, they are less by 3, i.e. Eq. (8.75) here and in the second edition is Eq. (8.72) in the first edition.

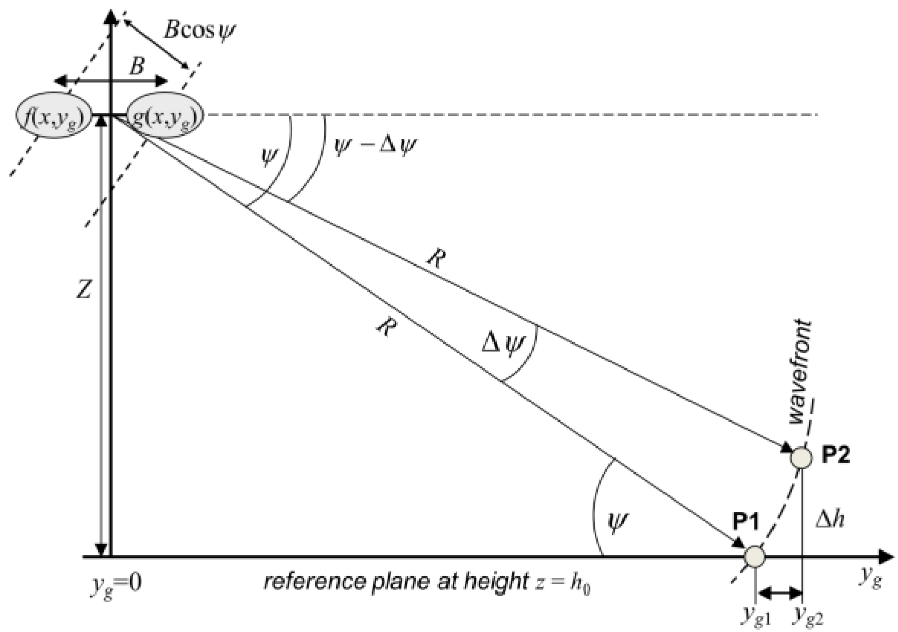

Figure 8.38: Geometry for interferometric height estimation.

Now consider the two scatterers **P1** and **P2** at ground ranges y_{g1} and y_{g2} as illustrated in Fig. 8.38. Both are at the same slant range R, but one is at an elevation $z = h_0$ relative to some unknown reference plane while the other is at an elevation $z = h_0 + \Delta h$. They are observed from two distinct radar apertures at an altitude $z = h_0 + Z$ and separated horizontally by a *baseline* B.[8]

[8] The results here are generalized to include use of a common transmit aperture and two independent receive apertures in (Richards, 2013). Both one- and two-transmitter versions of IFSAR are of practical importance.

Correction to portions of Section 8.6.1, "The Effect of Height on a SAR Image", beginning p. 489 (second edition) or p. 437 (first edition). Includes corrections to text and equations, and modification of Fig. 8.38.

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Each aperture independently transmits a radar waveform, receives the data, and forms a complex SAR image of the scene; these images are denoted by $f(x, y_g)$ and $g(x, y_g)$. The baseline should be orthogonal to the flight path; therefore the direction of the aircraft motion is into the page.[9] The radar range is great enough that the incoming wavefront can be considered planar. If the depression angle from the middle of the baseline to **P1** is ψ, the difference in range to the two aperture phase centers is well approximated as $B\cos\psi$. The difference in received phase at the two apertures then becomes, using Eq. (8.74)

$$\phi_{fg} \equiv \phi_f - \phi_g \approx -\frac{4\pi}{\lambda} B\cos\psi \tag{8.75}$$

Now consider scatterer **P2**, having the same slant range as **P1** but elevated by Δh meters. Because the radar measures time delay and thus slant range, the echo from **P2** will be indistinguishable from that of **P1**. Assuming an approximately planar wavefront at range R, Fig. 8.38 shows that the difference in ground coordinates is approximately

$$y_{g2} - y_{g1} \approx \Delta h \tan\psi \tag{8.76}$$

Because basic SAR images are two-dimensional, **P2** will be imaged at ground range y_{g1}.[10] The imaging of the elevated scatterer at an incorrect ground range coordinate is termed *foreshortening* or *layover* because the scatterer appears to have been shifted toward the radar. As illustrated, the layover is only in the range coordinate. In squinted operation, layover occurs in both range and cross-range; details are given in (Sullivan, 2000) and (Jakowatz et al., 1996).

The difference in the depression angle from the center of the IFSAR baseline to **P2** versus the angle to **P1** caused by the height difference Δh can be found by differentiating Eq. (8.75) with respect to the grazing angle:

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[9] The two apertures could also be displaced vertically, with similar results.

[10] SAR images are naturally formed in the slant plane, but are usually projected into the ground plane for display.

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$$\frac{d\phi_{fg}}{d\psi} = \frac{4\pi}{\lambda} B \sin\psi \quad \Rightarrow \quad \Delta\psi = \frac{\lambda}{4\pi B \sin\psi} \Delta\phi_{fg} \tag{8.77}$$

This equation states that a change in the *interferometric phase difference* (IPD) of $\Delta\phi_{fg}$ implies a change in depression angle to the scatterer of $\Delta\psi$ radians. To relate this depression angle change to an elevation change, consider Fig. 8.38 again. Examining two right triangles shows that $Z = R\sin\psi$ and $Z-\Delta h = R\sin(\psi-\Delta\psi)$. Eliminating R and applying a trigonometric identity gives

$$\begin{aligned} Z - \Delta h &= \frac{Z \sin(\psi - \Delta\psi)}{\sin\psi} \quad \Rightarrow \\ \frac{\Delta h}{Z} &= \frac{\sin\psi - \sin(\psi - \Delta\psi)}{\sin\psi} = \frac{2\sin\left(\frac{\Delta\psi}{2}\right)\cos\left(\frac{2\psi - \Delta\psi}{2}\right)}{\sin\psi} \end{aligned} \tag{8.78}$$

Assuming $\Delta\psi$ small and applying a small angle approximation gives

$$\frac{\Delta h}{Z} \approx \frac{\Delta\psi}{\tan\psi} \tag{8.79}$$

Finally, using Eq. (8.79) in Eq. (8.77) gives a measure of the relationship between the change in the IPD for a given pixel and a change in scatterer elevation above the reference plane (Carrara et al., 1995)

$$\Delta h = \frac{\lambda Z \cot\psi}{4\pi B \sin\psi} \Delta\phi_{fg} \tag{8.80}$$

Equation (8.80) is the basic result of IFSAR.